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Abstracts

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Finite Element Modeling of Fingertip Under Dynamic Loading

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Introduction

The responses of a fingertip to impinged vibration have been explored in a number of experimental studies to gain insight into its biodynamic characteristics, peripheral circulation, neurological function, and potential injury mechanisms. These studies have provided practical objective methods for assessing the health effects of prolonged exposure to hand transmitted vibration. The theoretical analyses, however, have been limited to simple linear and lumped-parameter system models to estimate the global vibration response of the human hand. The studies on localized responses of the fingertip and associated soft skin tissues have not yet been attempted. It is anticipated that the fingertip responses to static and dynamic loading can be investigated through development and analyses of finite element (FE) based models. The results derived from such models could provide considerable insight into the effects of dynamic loading on the stress and strain fields within the fingertip tissues and the deformations of the arterial vessels. The goal of this study is to develop a preliminary two-dimensional FE model of a fingertip to predict its response to dynamic loading that may be encountered while grasping and operating a hand-held power tool.

Method

A two-dimensional, nonlinear FE model of a fingertip is developed, as shown in Figure 1. The model incorporates the essential anatomical elements of a fingertip, such as soft tissue, bone, and nail, and nonlinear and asymmetric visco-elastic properties of the soft tissue. The dimensions of the fingertip are assumed to be representative of the index finger of a male subject. The interaction between the fingertip and a vibrating machine tool or handle is represented by a smooth contact between the fingertip and a steel plate. At $t = 0$, the finger was just in touch with the steel plate with zero resultant contact force. The fingertip is assumed to be symmetric about the compression-tension axis, such that the half of the cross section is used to derive the model. The soft tissue is assumed to be nonlinearly visco-elastic, while the nail, bone, and steel plate are considered to be linearly elastic. All material properties of the soft tissue, bone, and nail were obtained from experimental data reported in the literature (PAN et al., 1998). The simulations were performed by fixing the center of the bone, while the steel plate was subjected to prescribed motions in the vertical direction.

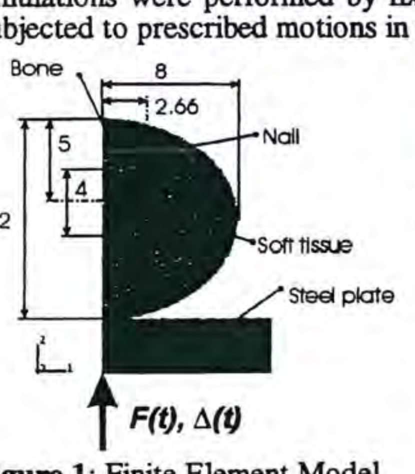

Figure 1: Finite Element Model

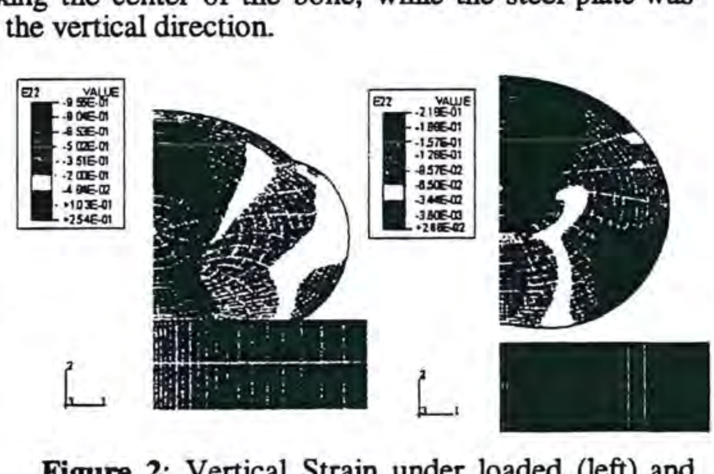

Figure 2: Vertical Strain under loaded (left) and un-loaded (right) states.

The time- and frequency-dependent deformation properties of the soft tissue were investigated by imposing different magnitudes of ramp-like loading of the fingertip with different ramping periods and sinusoidal vibrations of the contacting plate at two discrete frequencies (1 Hz and 10 Hz). The simulations also permitted the study of the effect of rate of loading.

Results

Figure 2 illustrates the distributions of strains along the vertical direction of the fingertip under loaded and unloaded states. In this simulation, the fingertip tissue was compressed to a peak deformation of 3 mm within a ramping period, Tc = 1.0 s. At $t = Tc$, the tissue experiences a large deformation and the local strain in the vertical direction, near the contact surface, approaches a value as large as -95% (Figure 2). As the vibrating contact plate returns to its original position at $t = 2Tc$, the fingertip tends to lose contact with the plate but the tissue exhibits some residual strain. The loss of contact between the fingertip and the vibrating surface occurs under large magnitude or high frequency motions, and is attributed to hysteresis or delayed deformation behaviour of the tissue.

The dynamic response characteristics of the fingertip under cyclic loading were investigated by applying a sinusoidal motion to the contacting plate. The tissue was initially compressed under a ramp displacement of 3 mm, and the position of the contact surface was held constant for 10 s to achieve a steady value of the contact force. A sinusoidal displacement (amplitude = 0.5 mm) was then applied to study the responses under dynamic loading. Figure 3 shows the time history of the deflection responses of tissue at different depths from the skin surface and nail, and the resultant contact force at a cycling frequency of 1 Hz. The contact force approached zero during the unloading portion of the cycle for both excitation frequencies (1 and 10 Hz), indicating a loss of contact between the fingertip and the plate. The ratio of the separation duration over the total cycling period increased with the increasing excitation frequency.

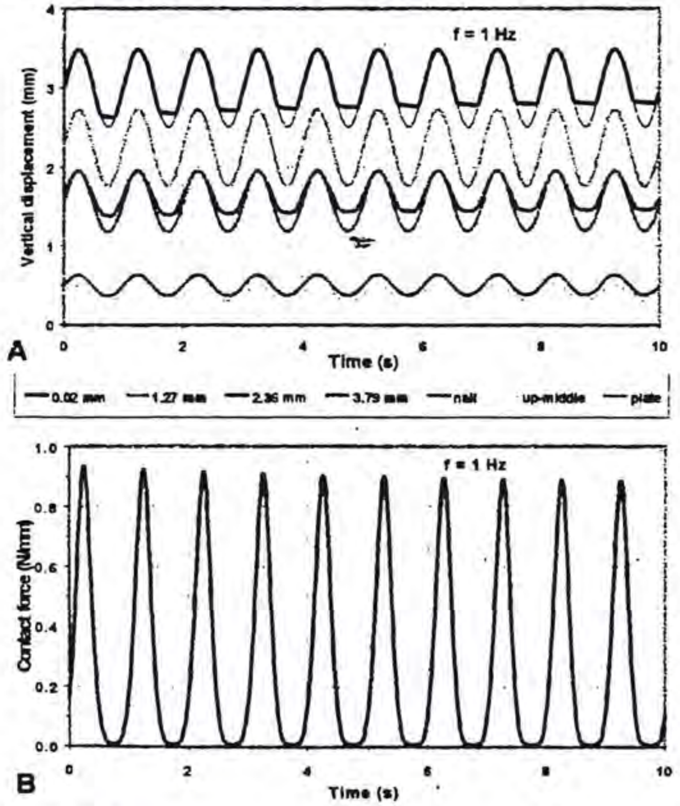

Figure 3: Responses under cyclic loading.

Conclusions

A preliminary FE model of a fingertip comprising anatomical structures of the fingertip and nonlinear visco-elastic properties of the soft tissue is proposed to study its response to static and dynamic loading. The model is capable of predicting the time-dependent stress/strain distributions within the soft tissues, contact force, and local deformations. Further enrichment of the model is desirable for realizing effective analytical tools for the study of vibration response of the human hand structure.

Bibliography

PAN, L., ZAN, L., FOSTER, F.S., Ultrasonic and viscoelastic properties of skin under transverse mechanical stress in vitro. *Ultrasound Med Biol*, 1998, 24(7), pp 995-1007.